R E P O R T R E S U M E S

ED 011 955 24 AA 000 074

PERCEPTUAL LEARNING IN EDUCATIONAL SITUATIONS.

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REPORT NUMBER BR-5-1213 PUB DATE OCT 66
CONTRACT OEC-6-10-156
EDRS PRICE MF-$0.09 HC-$1.36 34P.

DESCRIPTORS- *PERCEPTUAL DEVELOPMENT, *COGNITIVE PROCESSES, RESPONSE MODE, *STIMULUS BEHAVIOR, *PATTERNED RESPONSES, DISCRIMINATION LEARNING, LEARNING EXPERIENCE, *LEARNING THEORIES, ITHACA

BOTH COGNITIVELY-ORIENTED AND RESPONSE-ORIENTED THEORIES OF PERCEPTUAL LEARNING ARE DISCUSSED AND CONTRASTED WITH A STIMULUS-ORIENTED THEORY. PERCEPTUAL LEARNING IS DEFINED AS AN INCREASE IN SPECIFICITY OF DISCRIMINATION OF THE STIMULUS INPUT. THE AUTHOR DESCRIBED WHAT IS LEARNED IN PERCEPUTAL LEARNING AS () THE DISTINCTIVE FEATURES OF THINGS, (2) INVARIANTS OF EVENTS OVER TIME, AND (3) HIGHER ORDER STRUCTURES OF BOTH THINGS AND EVENTS. WHAT IS LEARNED WAS SAID TO BE SELECTED BECAUSE IT PROVIDES A "REDUCTION OF UNCERTAINTY." FOUR PRINCIPLES THAT ARE IMPORTANT IN THE APPLICATION OF THE AUTHOR'S VIEW OF PERCEPTUAL LEARNING TO EDUCATION WERE STATED--(1) TASKS CAN BE ANALYZED INTO UNITS OF PERCEPTUAL CONTENT WHICH FORM HIERARCHIES, (2) LOWER ORDER UNITS ARE DISTINGUISHED BY DISTINCTIVE FEATURES, (3) HIGHER ORDER UNITS ARE DISTINGUISHED BY STRUCTURE, (4) THE STRATEGY OF EXPLORATION AND PERCEPTUAL SEARCH DEVELOPS WITH AGE AND EDUCATION. THIS PAPER WAS PREPARED FOR THE SYMPOSIUM ON RESEARCH APPROACHES TO THE LEARNING OF SCHOOL SUBJECTS (UNIVERSITY OF CALIFORNIA AT BERKELEY, OCTOBER 28-29, 1966). (AL)

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BR-5-1213-3
PA 24
OEC-6-10-156

Paper for Symposium on "Research Approaches to the Learning of School Subjects," Univ. of California at Berkeley, October 28 and 29, 1966

Perceptual Learning in Educational Situations

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I am particularly glad to have the opportunity to talk to this symposium about perceptual learning and its role in education, for it seems to me to have been overlooked or treated as an unworthy stepchild while other kinds of learning have been pampered in the laboratory and offered as models in educational circles. A recent book edited by Melton, "Categories of Human Learning," provides an example of this neglect. Presumably a taxonomic review of prototypical learning situations and issues deriving from them, the book includes chapters on classical and operant conditioning, rote verbal learning, probability learning, short-term memory and incidental learning, concepts, problem solving and perceptual-motor skills. The nearest thing here is "perceptual-motor skills." But learning to hit a baseball or perform a tracking task is not the prototype of perceptual learning.

Exploitation of concepts from learning theory in Education has not, over the years, been very impressive. What has received plenty of attention (perhaps all it merits) is programmed learning, whose theoretical underpinnings (such as they are) derive from operant conditioning. Concept learning has had a certain success in educational circles too, made fashionable by Piaget's influence. As a colleague of mine said after observing him at a conference of educators, "The air seems to part in front of him as he enters the room."

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Why should perceptual learning have been so neglected, both by scientists and educators? Perhaps because people think of perception as having to do mostly with pictures--and indeed Gestalt psychology left many students with the impression that the laws of perception are based entirely on two-dimensional drawings. Or on the other hand, perhaps they think it has to do just with SPACE, so the educational implications would be only for mastering new means of locomotion, such as landing a plane. "School learning" is generally thought of as involving neither pictures nor space but symbols--numbers and words. As a result, verbal association and conceptual rules have seemed the obvious principles to lean on. But, as I hope to show you, symbols must be differentiated before they can be associated with anything, and rules are minimally effective as mere verbalized relations. Structural constraints must be perceived as well as verbalized.

The real reason, however, that principles of perceptual learning have not found wide application in education is that no one has thought much about the principles, or made it very clear what perceptual learning is. I am forced to try, therefore, to tell you what I think it is, and what its useful principles are. Only then can I give you examples of its implications for learning school subjects. The plan of my paper, therefore, will be to consider first the nature of perceptual learning and second to introduce some applications to learning in school situations. By applications, I mean psychological analysis of the task and skill to be acquired, rather than a list of recommendations for teachers, but I would hope the latter might eventually follow.

A THEORY OF PERCEPTUAL LEARNING

A decade or so ago, my husband and I published an article which we

called "Perceptual Learning: Differentiation or Enrichment?" It was the result of a debate with Leo Postman, in which we took the view that perceptual learning was basically differentiation of the stimulus situation, rather than accrual of contextual associations or cognitive elaboration. Postman (1955) argued that enrichment by images or cognitive context was not the necessary alternative to differentiation, and stressed a view more consistent with modern behaviorism, emphasizing response-learning.

There are indeed several alternatives and in order to make my own position clear I should like to state them. They have in common the fact that they are all <u>additive</u> mediation theories, a term which I think characterizes them better than our earlier term, <u>enrichment</u>. They can be classified into cognitively-oriented and response-oriented theories, in contrast to one which is stimulus-oriented. Cognitively-oriented theories can themselves be divided into several kinds. One of them considers perception as a kind of submerged problem-solving process, with development occurring as experience piles up assumptions on which inferences may be based. Originally Helmholtzian, this view has many present-day spokesmen such as the transactionalists, and, with his own flourishes added, Bruner (1957), who thinks of the process as one of trial and check of hypotheses and of categorizing. Another view is that perception develops through the formation of a schema. As experience accrues, the schema is elaborated and the impoverished stimulus can then be filled in by the richer schema to afford a more sophisticated percept. Bartlett's use of the schema in analyzing remembering was borrowed by M. D. Vernon (1955), his student, for her analysis of perceptual development. Piaget, of course, uses the concept of schema in a somewhat similar way--perception involves matching input to a schema and "accommodating" to it, though he stresses somewhat more the active nature of the process.

The response-oriented theories can also be divided into two kinds. One is the party-line theory of the Soviet perception psychologists, who refer to it as the "reflection" theory (Leontiev, 1957). I prefer the term "motor copy." Very simply, perception reflects the world by making a motor copy of it. A child palpates an object given him to identify first with gross and later with skillful exploratory movements, his "image" of the object improving and coming closer to the reality as exploratory movements develop. This is another kind of schema theory, similar to Piaget's and also to Hebb's (1949) who proposed that eye movements tracking the contours of objects resulted in the building up of cell assemblies corresponding with visual form perception. The Soviet psychologists go along with the relation of eye movements to form perception, action literally "mirroring" the object. Exploratory eye movements do develop in children, as research in this country as well as in Russia has shown, but I would quarrel with the notion that making a copy is fundamental to perceptual development.

The response-oriented theory most popular among American psychologists is not a copy theory. It goes by the name of "acquired distinctiveness of cues." The idea was first expressed, as far as I know, by William James who spoke of two "terms," originally confusable, being "dragged apart" by more distinctive associations which they had acquired. Miller and Dollard (1941) recast the theory into behavioristic terms and added the notion of acquired equivalence. The notion of additive mediation can be seen quite literally in this theory. Two stimulus displays, originally confusable, acquire distinctiveness through association with different and distinctive responses that provide "little s's" so that the sum of stimulation is now different. Additive mediation can presumably result in equivalence, too, if identical responses are associated with

different stimuli. The typical experiment for investigating this hypothesis consists of teaching subjects in an experimental group verbal labels for unfamiliar visual shapes such as those contrived by Attneave and Arnoult and then showing in an ensuing discrimination test that they are more easily differentiated than in a suitable control condition (Arnoult, 1953). The big difficulty here, of course, is to know whether it is really the distinctive responses that add distinctive cues to the visual stimulation.

In one way this theory of acquired distinctiveness is more like my own theory than the others are because it emphasizes an increase in differentiation as the fundamental characteristic of perceptual learning. But in another way, it is worlds apart, for it makes the assumption that the stimulus must be supplemented by more stimuli, arising from response mediators, to account for learning. I do not accept this assumption and would assert, instead, that stimulation is already full of information and that perceptual learning consists of detecting the relevant information, filtering the distinctive features from the irrelevant or noisy input. This is a drastically different idea--perceptual learning is not addition but reduction. To convince you of its truth, I must go on and explain in more detail four points: (1) what I see as the criterion of perceptual learning; (2) what is learned in perceptual learning; (3) some taxonomy for the area; (4) and the way in which I think the learning occurs.

Definition of Perceptual Learning

The criterion for perceptual learning, as my husband and I argued in our old article, is an increase in specificity of discrimination of the stimulus input. I would still accept this--what is orginally perceived as homogeneous, random or confusable becomes differentiated.

The experimental example which we gave will still do as a simple prototype, though I shall later provide some needed taxonomy. The experiment made use of a number of pictures of coiled lines that had been constructed to vary in three ways, the number of coils, degree of horizontal compression, and orientation with respect to other members of the set (some were reversals of others). One of the pictures, printed on a card, was shown to the subject with the instruction that he was to examine it carefully so as to recognize it again. Then it was inserted in a deck of cards containing all the pictures, as well as others identical with it. The subject was told to look at each of the cards and to pick out those identical with the standard. After one run through the pack, it was shuffled, the standard shown again with fresh exhortations to examine it carefully, and a new run made.

Our interest in this task was in the subject's errors and their rate of decrease as the runs continued, for they did decrease. A group of adult subjects reduced the number of cards confused with the standard from a mean of 3 in the first run to zero in an average of 3 runs. Children of an intermediate age (around ten) reduced the confusion errors from 8 to none in a mean of 5 runs. Younger children (around seven) had a mean of 13 confusion errors on the first trial. In a mean of 7 trials the errors were reduced to a mean of 4, but most of these children did not achieve perfectly specific discrimination before exhaustion set in. In all the subjects, however, perceptual learning in the sense of an increase in specificity, occurred, without reinforcement or assignment by the experimenter of distinctive responses. Errors were related to the number of distinctive features in common; that is, a card differing by only one feature from the standard, say in degree of compression, was more often confused with it than one differing in two or more features.

The achievement here, I think, is coming to perceive as unique something which was not, in the beginning, readily distinguishable from other members of the set. What is it that has been learned?

What is Learned in Perceptual Learning?

What is it that is learned as perceptual differentiation increases? I have already said that I do not think it is responses, or a schema, or a representation. Of course I would not deny that responses occur or that representations of objects may develop. But I do not think that they are propadeutic to, or the basis of perceptual learning. I think what is learned are distinctive features of things, invariants of events over time, and higher order structures of both. These three properties have something in common for the perceiver, as I shall show later, but they need to be distinguished, too, for reasons of taxonomy. Let me say a little about each of them.

Distinctive features. I have borrowed the term "distinctive features" from Roman Jakobson, who with Morris Halle analyzed them for phonemes, the smallest units of speech (Jakobson and Halle, 1956). Phonemes can be differentiated from one another by their bundles of distinctive features, each one being unique. The features are contrasting differences on a dimension or property of the members of a set. In the case of phonemes, examples of contrasts are grave-acute, lax-diffuse, vocalic-non-vocalic, and so on. Jakobson's list of 12 is enough to differentiate all the phonemes of all languages. The features are relational, for they must be invariant over various transformations, such as different speakers and intensities. Only differences, obviously, carry information for discrimination, and it seems reasonable to expect that, for the most part, they must be learned, though it may be, especially with precocial animals,

that nature provides a small vocabulary of properties which are attention-getters at birth.

Two psychologists also used the term distinctive features more than 20 years ago. They were Robert Gagné and James Gibson who were investigating during World War II means of improving training for aircraft recognition (Gagné and Gibson, 1947). In a comparison of two methods over a number of classes of airmen, they found that teaching contrasting distinctive features of the various planes was more effective than a system purported to promote fast recognition of a total "Gestalt." The students themselves emphasized that only the differences should be taught.

Recognition of faces as it develops in infants seems to be a nice case of learning distinctive features in early development, though our knowledge of the process is not yet so refined as to permit definition of contrasts. At one to two months, a cardboard oval with spots, small squares or angles where eyes would be elicits marked attention and even smiles (Ahrens, 1954). By three to four months, realistic eyes on a dummy or cardboard oval are necessary, and after that a nose portion, but not the mouth. By five to six months, the mouth begins to emerge as a feature commanding attention, especially when in motion. By six months, a widely drawn mouth is more effective in eliciting smiles than a pursed mouth. By six to eight months, the infant begins to differentiate one adult face from another. It can differentiate bundles of distinctive features so as to identify a given face as unique.

Besides distinguishing objects in his world by learning their feature differences, the human child learns distinctive features of printed displays of all kinds; pictures, letters and numbers. I have been particularly interested in analyzing the distinctive features of letters (see Gibson, 1965). Improvement

in discriminating letter-like drawn shapes continues up to nine years or so, and I am very concerned with what changes developmentally to render this process more accurate and more economical. One letter may differ from another in ways that are not critical, not invariant distinctive features, as well as in ways that are. A five- or six-year old has simply not got, as yet, the vocabulary of features that are critical filtered from the noisy ones, and may make a decision on some irrelevant feature such as size. We have been trying to teach a small portion of the alphabet to four-year-olds this summer, and were struck by the remarkable difficulty of the task for them. They had much farther to go than we thought. But the two who finally succeeded were able, in transfer tests, to disregard noisy and partially redundant features that were not distinctive contrasts, though they had not been specifically taught to do so.

Invariants of events. While one can speak of distinctive features of events, such as a rhythmic property of a musical phrase, it is discovery of an invariance over time that best characterizes perceptual learning for events. The spatial constancies are prime examples. When an automobile approaches me, I do not perceive it as a different vehicle from one microsecond to the next, although its projected image on my retina is in constant change. I perceive it as the same car, coming nearer. It is out of such events, involving time and motion, that perceptual constancy develops, I believe. Continuous change is important, because it permits extraction by the observer of a rule, a mathematical invariant relating properties of stimulation over a temporal change. Events, in short, are units in time. We can only speak of events if there is some invariant giving unity.

Shape constancy as well is extracted through observation of events such as the continuous turning of an object in space or walking around it. An infant

can give himself opportunities to discover the invariant relations in events by moving his hands toward himself, or toward each other (in which case size-distance features of the stimulus do not change) or by rotating objects. Piaget (Piaget and Inhelder, 1956) claims that infants actually experiment in this way to learn geometrical invariants and rules for happenings in space and time. His intellectual emphasis I would be cautious in accepting, but that extraction of invariants of events is an important kind of perceptual learning I am sure.

Studies of the development of conservation in children, following Piaget, have emphasized the role of verbalization. Some new intellectual operation comes in, they would have it, and in the words of Bruner, "It is plain that if a child is to succeed in the conservation task, he must have some internalized verbal formula that shields him from the overpowering appearance of the visual displays..." (1964, p. 7). But if this is true, we must account for the genesis of the verbal formula. Simply telling the child does little good (Wohlwill and Lowe, 1962). It seems to me that the child shifts from judging by the features of a static display to discovery of the invariance in the event. For example, a five-year old who sees water poured from a tall thin jar to a fat squat jar, may judge quantity on the basis of some size aspect of the jars and thus fail to "conserve." He has to see the continuity of the water over shape transformations before he can perceive a unit event in time. The more complex the transformations--e.g., the greater the differences in size and shape of containers--the harder this is. Anything that destroys continuity in the event by calling attention to the stationary display reduces the chance of perceiving invariance in the event, whereas enhancing continuity by centering attention on the pouring facilitates it (Bruner et al., 1966, pp. 193 ff.). One can read about conservation of mass in a book, but I cannot believe that the scientists

who first made statements about it did not begin by perceiving invariance of a property over time and despite transformations which they learned to ignore or compensate.

Perception of causality, the least understood of the constancies, is again the extraction of invariance from transformations in the course of an event. A rolling billiard ball bumps another, and the loss of its own velocity is compensated by that gained by the second. Michotte (1954) has convinced most of us that the perception of "cause" here--though I should prefer to say the invariance--is as direct as that of modal qualities of objects, such as color. I would want to see more work on this with children before I would agree that no perceptual learning is involved. But in any case, the observation is the kind that lies at the very base of science education.

Higher order structure. My third category of "what is learned" in perceptual learning, higher order structure, applies both to objects and events. Perceptual development, in the case of objects, begins by detecting distinctive features and unique bundles of them for sets of objects. But the bundle of distinctive features of an object may possess higher order relations between the features, or there may be redundancy of many orders in the correlation of features. Perception of these relations, and of high order redundancies is a sophisticated achievement and one which should be of great concern in studying perceptual learning, for it is here, in particular, that one senses a possible contribution to education. Perception of regularity, and higher order constraints obviously frees the information processer to increase enormously the input he can handle.

For a simple example, let us return to development of the infant's perception of faces and facial characteristics. There is evidence that assembly

of a vocabulary of features is prior to detecting higher-order relations. Perception of facial expression develops late, and this is a case of noting invariant relations over different faces. Again, discrimination of a pretty face from a not-pretty one is late, not only because cultures have conventions about this, but because the redundancies involved--symmetry, ratio of length to breadth, and so on--are not first order features.

That second and third-order constraints are slower to be picked up seems obvious, and there is evidence that this is the case in work on information processing in adults (Oostlander and DeSwart, 1966). It takes longer to process them at first and in children they may not be utilized at all; but practice in perceiving them can be very effective. Let me remind you of Bryan and Harter's (1899) classic experiment demonstrating progress from receiving lower units to higher units in learning telegraphy.

That young children are slow to perceive and utilize regularities and redundancies which adults find obvious is illustrated by an experiment of Munsinger's (1966). Subjects were shown projected shapes, one at a time, varying in number of angles in the shape. The number of angles was always 5, 10, 20, or 40 and the subject was told to report one of these numbers when the shape was exposed. Redundancy was varied by projecting shapes of a given number of turns on background colors which might or might not be a one-to-one contingent relation, a partial redundancy, or no systematic relation. Children of two age groups and adults were subjects. Accuracy of the adults increased following the linear contingency, but it did not for children. They were not sensitive to the internal constraint among the variables and did not improve in the course of the experiment. The adults appeared to be insensitive to all except the one-to-one contingency relation, but

practice might have changed this finding.

An experiment by House (1966) with retarded children presented discrimination learning tasks with dot patterns as stimuli. The patterns varied in redundancy and in form of redundancy (symmetry as opposed to repetition without reflection). Ease of discrimination was related to both. Symmetry, continuous lines, and distinctive clusters of dots were generally utilized by retardates but order of other kinds such as repetitive relations between sub-patterns might or might not be effective. She concluded that failure in these children was due to a perceptual deficit, inability to perceive the pattern differences as described by these structural characteristics.

Taxonomy of Perceptual Learning

What is learned in perceptual learning, distinctive features, invariants, and higher-order structure, can be recognized in several different "media," and these media give us a simple and convenient taxonomic classification. The media describe aspects of the world, man's ecology, not differences in process. This is the right basis of classification for a stimulus-oriented theory. Perceptual differentiation occurs within five media; objects, space, events, representations, and symbols. The child's earliest perceptual development is greatly concerned with objects and space (space close-by, at least), and more later with events, as he achieves locomotor and manipulatory abilities. Learning with pictorial representations and symbols is still later and most of what I shall have to say about school learning is concerned with perceptual learning in these media.

Learning Principles

I have said that I am convinced that perceptual learning is a reduction,

not an addition. You will not be surprised, therefore, that I do not choose association as the ultimate principle of such learning. I think, instead, that filtering is the right concept. Distinctive features, invariants, and structure (rules, if you like) are not integrated but rather filtered or extracted from noisy and irrelevant input. They are, in James's sense, dissociated rather than associated.[1]

How does this happen? In terms of factors facilitating learning, anything which enhances distinctive features or impoverishes noisy background in relation to them should help; exaggeration of contrasts in the case of distinctive features, and "showing the bones" in the case of structure. There is a summer course at Andover in "Perceiving" which aspires to teach structure in nature. The methods are "Bauhaus" methods used by Maholy Nagy at the Chicago Institute of design. One exercise is slicing an onion and printing the cross-section on paper or cloth as a design. Another is taking rubbings of tree bark as illustrations of textural regularity in nature. These seem to me ingenious because by printing the structure, it becomes dissociated from the objects so as to reveal and enhance it.

Mostly, however, there is no teacher to point out contrasting features and to separate the pattern from the partially correlated but non-critical aspects. The child does it himself, and I think he does it very actively. Perception is active, not in the sense of performance or execution, but in the sense of exploration. Attention to aspects of the environment is demonstrable in very young infants, as Fantz (1965), Kesson (Salapatek and Kesson, 1966),

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1. "What is associated now with one thing and now with another tends to become dissociated from either, and to grow into an object of abstract contemplation by the mind. One might call this the law of dissociation by varying concomitants." (James, 1890, Vol. 1, p. 506)

and others have shown us. This early attention seems to be a kind of capture by compelling stimulus properties, and the shift to voluntary attention, indicated by directing the regard, turning the head, and canvassing the environment in a more and more systematic search pattern develops only gradually. But perceptual development is characterized by exploratory movements of the sense organs, a search for distinctive features and invariants. It seems to me that the motivation is primarily "curious" or "intrinsic" as Berlyne (1966), Hunt (1965), and others have called it, unlike the motivation of most performatory behavior.

The big question which I am always asked at this point, is what is the selective mechanism in perceptual learning? Is a distinctive feature selected as relevant because it wins a reward, gets confirmation or external reinforcement? Although this could happen in a teaching situation, I think that it is not the true selective principle of perceptual learning. So much of it goes on in infancy and is somehow self-regulated; nobody is giving out M and Ms, or slaps or even praise. I think the reinforcement is internal--the reduction of uncertainty.

Stimulation is not only full of information, it is too full of information to the neonate, or to the underprivileged child who lives, I am told by the experts, in a world of confusion and apparent disorder, or to the first grader presented with a reader, or to a school-boy given his first algebra text. Reducing this information is the goal and the end of perceptual learning. The invariants are there in the stimulus, but so is a lot of noise and irrelevant information. Distinctive features, invariants and higher order structure have exactly the function of reducing uncertainty, filtering the gold from the dross, making one out of many and thus allowing more information to be handled.

Garner (Garner and Clement, 1963, Royer and Garner, 1966) has pointed out in clever experiments that the "good" pattern or structure is the unique one. This fits too. The good one is the highly differentiated one that is not confused; it has specificity within the set and it stands out from the noise. Specificity and "uniqueness" are not automatically appreciated by the perceiver. They can be predicted for various displays by the wise experimenter; but perceptual knowledge is required for the detection of univocality in sets of any complexity.

To conclude what I can say in this short time about perceptual learning: it is defined as increase in specificity of stimulation to discrimination; what is learned are distinctive features, invariants in events, and structural regularities; and these are learned, that is to say filtered from the total stimulus, because they serve the function of reducing uncertainty.

APPLICATIONS TO EDUCATION

Now I want to tell you some ways in which this view of perceptual learning can be usefully applied to education. I have four points to make. I would like to say "principles," but that would be sheer ostentation. I will illustrate my four points with examples from "school learning." I must make one more distinction before presenting them, the distinction between content and strategy in a task. This is a useful distinction rather than a profound theoretical one, for the two are not easily divorced in actual operation. I am willing, however, to be a structuralist and a functionalist at the same time. I want to talk about units of content of perception and also about active perception, for being a learning theorist, I conceive of perception as active, exploratory and directed rather than passive reception of anything exposed to the sense-organ.

Units

My first point is that tasks can be analyzed into units of perceptual content which form hierarchies. I think that task analysis is essential for a theory of instruction as well as for a theory of learning. A task varies at different stages of mastery and the optimal skill at the end may bear very little resemblance to the skill at the beginning, but there is an order in the progress. For any task, therefore, I want to talk about lower order units and higher order units. The order of the perceptual unit changes with the stage of learning, progressing from lower to higher. I have a good precedent in making this statement, for Robert Gagné (Gagné, 1962) made such analyses for learning mathematics and showed their usefulness in setting up a program of instruction. It has been shown, furthermore, that the factor structure of a task changes with stage of mastery. Fleischmann and Fruchter (1960) showed this for learning Morse code; in early stages, achievement was best predicted by tests of fine discrimination of details but later by tests of "Gestalt" perceiving, grasping of "wholes." Elkind (1965) reported that tactual discrimination of letters correlated with reading achievement in its early stages, but not later, and this makes very good sense.

I would like to take reading as my example, since this is the task I have worked on. I think acquisition of reading skill can be divided into four phases or stages which overlap, but nevertheless have an order in that the earlier ones must precede the later ones. The first phase, which goes on for many years, is learning to speak. This precedes the others both practically and logically, for the writing system is a second order symbol system decoding to speech, itself symbolic. The second phase begins when the child is first presented with printed letters. He has to learn to discriminate them from one

another, for th[illegible] are the smallest units of the writing system from which words and sentences ar[illegible]uilt. It may seem to you trivial to distinguish such a stage, but I assure you it is no mean achievement. In fact, progress continues for several years. If you doubt it, try learning to distinguish the graphemes of an unfamiliar alphabet, such as Hindi or Arabic.

The third phase is learning to decode letters to sound. It sounds so easy--just a simple paired-associate learning task. But this is not the case, if you think about it, especially with English where sound-letter correspondences are by no means one-to-one. Letters are the smallest units of the writing system, yes, but the spelling-sound correspondences are not reducible to one sound for one letter or vice versa. This does not mean that there are no rules or order in the system; there are, indeed, but they can get fairly complicated. The child, if he is going to be a good reader, cannot learn by a sheer rote memory procedure, for he needs to learn the order in the system, the internal structure given by spelling patterns and syntax. He may start with rote learning, decoding simple words like "O see baby" to speech. The kind of reading vocabulary one would achieve by simply learning words with no transfer by rule would be severely limited. This may well be all that some people have. But we know that detection of structural constraints in the spelling system is possible, for it can be shown that skilled readers perceive pseudo-words fitting the rules far better than ones which do not. What we do not know is exactly how this order is picked up, and that is where my research is focussed at present.

This takes me to the fourth phase, which as I have shown already, must overl[illegible]che third, the learning of higher-order units. A good reader does not read letter by letter, decoding one at a time in sequence from left to right to

get the word. Research by Newman (1966) and by Kolers and Katzman (1963) has demonstrated dramatically how much easier it is to read a word presented simultaneously than the same word presented letter by letter. And we know from Cattell's (1885) classic work that with a fast exposure of less than 100 milliseconds, an adult can read about four unconnected letters, a ten-letter string if it makes a word and 20 or more letters if there are words forming a sentence (The dog barked at the cat). As redundancy is added, the good reader picks up bigger units.

I am sure there are examples of a shift from low-order to high-order units in other subjects than reading. In mathematics a child begins by handling numbers a digit at a time, but a skilled mathematician handles equations or whole theorems as units. Patrick Suppes tells me that when a child is learning the multiplication table, there is not just a slow constant decrease in latency of giving answers, but a sudden dive. As Suppes put it, the child has just acquired a "read-out." I would say that 7 x 9 = 63 has become a unit. I do not believe any tachistoscopic experiments of the kind we have done with reading have been done with arithmetic. I think it would be interesting and provide a method for studying unit-formation in mathematics.

Reading music is another obvious case for feature and unit analysis, and progression to higher units of structure, even to the pattern of a symphony.

Distinctive Features

Now I come back to distinctive features again, because my second point is that <u>low-order units are distinguished by distinctive features</u>. This is true for the content of school tasks as well as any others, but in the former case we have an obligation, as teacher-researchers, to find out what they are. In

my research on reading, I have spent a lot of thought and experimental time trying to analyze the distinctive features of letters. The type I chose was simplified Roman capitals. I began by working out simply intuitively a list of 12 features which would give a different bundle for each letter. This is not easy, as it turns out, but I got one that worked that I liked fairly well. The features were checked off for each letter as either present or absent. The ones included are

straight line
- vertical
- horizontal
- diagonal
- diagonal

curve
- closed
- open horizontally
- open vertically

redundancy
- symmetry
- repetition

intersection

terminal ending with
- left-right scan
- downward scan

We did an experiment with four-year old children, then, from whom we obtained a confusion matrix. We correlated the results with predictions from the feature list with only fair results. A multidimensional proximity analysis of the matrix was rather encouraging for a straight-curve and a diagonality dimension came out of it. We are getting a new confusion matrix with adults now. There will be less noise in the data, so it may take us farther.

I haven't thought much about features of units of other subjects, but I think reading a map in geography would be a nice one to play with. What characterizes a region as unique? I suppose mountains, rivers, lakes, timber,

deposits of ore and so on. I am reminded of a story of Bruner's; he gave a geography class a map of a real region with all these features indicated and asked them to locate a city, some towns and villages and a railroad. He promised to tell them afterward where these actually were. It was a very successful maneuver motivationally. Could it not be used for research on critical features too? Not only map-reading but ways of displaying an area most effectively on a map need research. What is the optimal critical information?

The Role of Structure

My third point is that higher-order units are distinguished by structure. It is perception of structure, that is, internal order, relations and correspondences that permits processing of bigger and bigger units. Lenneberg (1962) in speaking of grammatical rules says that they are rules of correspondence, a formalization of our ability to perceive similarity between physically different stimulus configurations. The child's first lesson in discovering structure and using rules comes in learning language. All the child needs to learn this lesson, apparently, is to hear plenty of it, but a child whose environment is impoverished in this respect misses his first lesson in discovering order and never catches up. It seems as if the learning of order in speech transfers to the discovery of order and structural relations in other spheres. As Lashley (1951) made so clear to us, the problem of serial order in behavior is the central one for psychology, but we have not gone very far in solving it.

In mathematics, order is obviously all-important. Structural principles such as similarity, equality, symmetry, transitivity, and congruence are essential concepts and to grasp them they must be made perceptible. I like especially an example of Wertheimer's from his book on "Productive Thinking"

(1945). He taught a young child (only five and a half) how to find the area of a rectangle, drawing it for him, filling it with small squares, counting them in various ways, and so on. Then he presented the child with a parallelogram and asked him if he could find its area. After some moments of puzzled staring at it, the child asked "Do we have a pair of scissors?" They were produced and he proceeded to snip a triangle off one end and fit it neatly on the other. Then he said, "Now I can do it." He literally perceived the solution.

A colleague of mine who is interested in teaching mathematics to quite young children described a venture of his in teaching the concept of moments by having the child draw marbles from a cup holding different numbers of red or green marbles. A listener said, "Why don't you derive it for them?" He answered, "It's a fact of nature. Sure there are axioms for deriving it, but first you have to discover it."

A more elaborate example of the value of making a complex mathematical function or geometric object or physical principle perceptible is the use of computer-produced perspective and stereographic representations, and animated movies to illustrate complex functions.[1] The computer renders, in terms of points and lines, a series of pictures that have been described to it in a more abstract way.

I mentioned earlier the importance of processing high-order units in reading, the units structured by morphological and syntactical rules as well as meaning. Teachers have always, I suppose, encouraged children to use

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1. These techniques are discussed in two articles in Science (Knowlson, 1965, and G. A. McCue and J. D. O'Keefe, 1966). Knowlson gives a fascinating description of a computer-produced movie by F. W. Sinden on "Force, Mass, and Motion."

redundancies contributed by meaning to help decode new words and to increase reading speed. In early stages of reading this can be a dangerous thing, not only because it often leads to wild guessing, but because it hinders learning the other important kinds of order, in particular the spelling patterns and spelling-to-sound correspondence rules. They may be hard to formulate (see Venezky and Weir, 1966), but nevertheless they seem to be infinitely valuable for reducing information.

Our research (the experiments with pseudo-words that I referred to) demonstrated that morphological generalizations are possible and transfer to the reading of new words. This learning has begun to occur by the end of first grade (at least in children from a superior educational background) with short letter-strings, and has advanced to perceiving order in somewhat longer ones by the end of third grade (Gibson, Pick and Osser, 1963). I think that development of learning sets for abstracting common patterns has something to do with this. Probably, also, redundancy of sound correspondences with the spelling patterns facilitates the extraction of patterns. How the generalization comes to be made is not an easy question to answer, since discrimination of words on the basis of differences of a letter or two is the obvious early accomplishment. A second-order generalization must follow differentiation, when regularities are perceived and used for transfer. We are working on this now, testing the value of a learning-set procedure for promoting abstraction of common patterns.

In experienced readers, still larger units than words are processed, the grouping principles probably including meaning and syntax. The influence of context on speed of reading has long been emphasized (Tinker, 1958; Morton, 1964), but the evidence for pick-up of word chains as units has not been too

clear, nor have the reasons for it. Does a skilled reader grasp more in one fixation just because he has increased his "span," which is a constant that has been "stretched" with exercise so that he "takes in more at a glance?" Advocates of practice with a tachistoscope (Renshaw, 1945) often seem to imply this. Or, on the other hand, are structural features of the material correlated with the larger units? Levin and Turner (1966) and Levin and Kaplan (1966) have provided convincing evidence of the latter proposition in new experiments on the eye-voice span, showing the influence of sentence structure in forming super-word units.

The eye-voice span is the distance that the eye is ahead of the voice in reading aloud. It can be measured by turning off the light at some point in the reader's delivery and seeing how far he can continue reading when the print is no longer visible. The reader can be stopped at a phrase boundary, or at any point before or after it which is interesting for syntactical or semantic reasons. Does the eye "reach," so to speak, for the end of the phrase, the structural unit, as a new fixation begins? This is a perfectly plausible hypothesis, since we know that peripheral vision contributes enormously to skilled reading. (If you don't believe it, try reading with occluders on your glasses which leave you only foveal vision.)

Some of the findings of Levin and his collaborators are as follows. The eye-voice span is significantly longer for structured sentences than for unstructured word lists. Eye-voice span increases, in general, with school grade. The eye-voice span tends to be longer <u>before</u> the verb in a passive sentence and longer <u>after</u> the verb in an active one. The number of times a subject reads to the end of a phrase unit, corrected for his <u>modal</u> eye-voice span, is significantly greater than zero. There is a tendency to read to phrase-

boundaries rather than to non-boundary positions, and older subjects do this significantly more often than do second graders. Most interesting of all, the eye-voice span is longer in the more highly constrained passive sentence form than in the less constrained active form.

The evidence thus supports the hypothesis that people tend to read in phrase units and that a person's span is not a constant of so many words, but rather shrinks or expands to accommodate to phrase boundaries, fluctuating with the degree of structural constraint in the sentence. Skilled readers do this more than beginning readers or slow readers. The purist may wish to argue that learning to read in phrase units is not just perceptual learning but involves short term memory. The eye-voice span technique does not allow us to settle such an argument, but in any case we can emphasize the importance of perceiving structure, however the information is processed in the on-going act of reading. Knowledge of structure, in combination with peripheral "reaching" directs the eye ahead in the sentence so as to complete one structural unit and begin another. More study of the grouping principles involved and of the way they interact with input in perception has highest priority for researchers working in this area.

Perceptual Strategies

My fourth point is that the strategy of exploration and perceptual search develops with age and education. Selective attention, the ability to focus on points of high information and to shut out the irrelevant is essential for discovering features and structures. It was the conclusion of a recent conference on disadvantaged children that attentiveness is the single most important cognitive attribute. Experiments of mine in collaboration with Albert Yonas

(Gibson and Yonas, 1966) studied visual search and scanning in children of different age groups. We found that speed and accuracy in finding a target improves with age, especially when the background is confusing. Experiments on dichotic listening by Maccoby and Konrad (1966) show that hearing one of two voices which are speaking at the same time improves with age. In both cases the person is shutting out the distraction so as to select the wanted information. This kind of perceptual strategy grows from birth to maturity.

Can one "train" attention in any way? In presenting an award for distinguished teaching, President Goheen of Princeton said that "when Louis Agassiz was asked his greatest achievement, he replied that he had taught men to observe."[1] I am sure there are individual differences in this trait; one thinks of Darwin on the voyage of the Beagle noting similarities and the course of differentiation over the world and finding the grand plan, the order over all. The great scientist, we feel sure, does this. How do we help a child to sort critical features from noise, to find order and regularity in the world, in particular in the school world?

I am not discouraged by the orthodox psychologist who says you can't talk about training attention or observation. That's the old faculty psychology, he says, and we were warned by people with famous names that it was wrong. We were, but we have found since that time that transfer is not simply a matter of common elements and individual bonds. Learning sets can be formed that are quite general and that are powerfully facilitating.

How do we help to build a set to observe? For one thing, we try to teach strategies, never answers. I can think of one strategy that comes as a

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1. Princeton Alumni Weekly, Feb. 22, 1966, p. 11.

moral from studying the perceptual constancies: How is the invariant discovered? It is discovered by observing motion--approach and withdrawal, rotation, moving projections from different angles. Moving things, or moving yourself in an orderly way is literally a good technique. Looking at something from another angle or from a distance often reveals structure. One of the dramatic examples is the geographer who went for an airplane ride and discovered, looking down on some hillocks in his own cornfield, the outlines of an old Roman fort. We can't often do this, but any trick that reveals what is invariant over change gives order and reduces information. My husband suggested a very ingenious experiment on this plan. A first-grader is shown the bent-stick illusion, a rigid stick on a pivot placed in a pan of water. He sees that the stick is bent. Then he is asked to walk around the pan, looking at the stick. He perceives, as he does this, that the bend shifts as he goes around and maybe, if he is clever, he perceives the invariant--the straight stick transformed by refraction, as revealed by a continuous change of station point in relation to stick and water.

Practice in categorizing by perceptual properties, especially graded ones, was a favored method of the Montessori system. Preschool education in Russia leans heavily on it today. I am not sure how useful it is. We badly need research in this area. I suspect that we want to give practice not so much in <u>ordering</u> things as in <u>finding</u> order. Habits of easy categorizing are to be avoided, for they threaten us with stereotypy, with blindness to the superstructure of greater value. Perhaps the best thing we can do, in our present state of knowledge, is to give a child plenty of things to observe, sets of things with an inherent order, and leave him in a non-distracting environment to manipulate them and find order. Finding a rule, reducing information,

is amazingly rewarding, as is seeing something interesting that you hadn't noticed before. An educator who can give a child this experience will have him looking forever.

CONCLUSION

I must conclude on a slightly pessimistic note. In the course of studying perceptual development and writing a book about it, I have become more and more convinced that an important part of perceptual learning, grasping the distinctive features of objects and the invariants of events, goes on very early in life. When formal education begins, much of this is done, or if it is not, in the case of a badly deprived child from an impoverished environment, it may be too late. Nevertheless, there is much for the educator to gain from principles of perceptual development. The young scholar must learn to differentiate the symbols of "book learning," and above all, he must be helped to discover the order in nature and language, in science and art.

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